Stock Assessments for British Columbia Herring in 1985 and Forecasts of the Potential Catch in 1986

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ABSTRACT

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Herring stock abundance in British Columbia waters was assessed for 1985, and forecasts were made for 1986 using two methods: (1) escapement method, and (2) age-structured model analysis.

The abundance of spawners in the 1985 herring run in British Columbia waters as assessed by the escapement method was 112,000 tonnes. The 1986 run is forecast at 143,000 t with average (1970-85) productivity. The 1986 forecasts for poor and good productivity are 113,400 t and 172,700 t respectively. For the south coast particularly it is anticipated that poor productivity will prevail, due to unfavorable environmental conditions.

The forecast biomass of the major migratory stocks from age-structured model analysis for 1986 is 130,300 tonnes. This predicted run size reflects the downward stock trends in the central coast and south coast and the predictions of poor recruitment because of the currently unfavorable environmental conditions for these areas.

The recommended 1986 catch level (20% of the weighted 1986 herring run size) for the B.C. coast is 14,800 t. This includes a recommended closure of the west coast of Vancouver Island where forecast stock biomass is below the CUTOFF level and a 800 t fishery in the Strait of Georgia where forecasts are only minimally above CUTOFF levels.

Key words: Clupea harengus pallasi, Pacific herring, stock assessment, forecasts, age-structured analysis.

RESUME

Haist, V., J. F. Schweigert and M. Stocker. 1986. Stock assessments for British Columbia herring in 1985 and forecasts of the potential catch in 1986. Can. MS Rep. Fish. Aquat. Sci. 1889: 48 p.

L'abondance des stocks de hareng des eaux de la Colombie-Britannique a été évaluée pour 1985, et des prévisions ont été faites pour 1986 à partir des deux méthodes suivantes: 1) méthode des échappées, et 2) analyse du modèle de la structure des âges.

L'abondance des géniteurs en 1985 dans les eaux de la Colombie-Britannique a été évaluée à 112 000 t, selon la méthode des échappées. On prévoit qu'elle atteindra 143 000 t en 1986 avec une productivité moyenne (1970-1985). Les prévisions de 1986 établissent les niveaux faible et élevé de productivité à 113 000 t et 172 700 t respectivement. Sur la côte sud, la productivité devrait rester faible à cause de conditions environnementales défavorables.

Le niveau de prises recommandé pour 1986 (20 %) du volume pondéré de géniteurs de 1986 a été fixé à 14 800 t pour la côte de la C.-B. Il a été recommandé c'interdire la pêche sur la côte ouest de l'île Vancouver, où les prévisions concernant la biomasse du stock sont en-deçà du niveau limite. Enfin, le niveau de prises pour le détroit de Georgie, où les prévisions excèdent tout juste les niveaux limites, a été établi à 800 t.

Mots-clés: Clupea harengus pallasi, hareng du Pacifique, évaluation des stocks, prévisions, analyse de la structure des âges

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FOREWORD

This report was prepared by the Herring Population Dynamics Program of the Herring Section (Fisheries Research Branch), and contains proposed catch levels for herring for the 1985/86 season. These recommended catches are based primarily on biological considerations, and may vary with those finally adopted by the Herring Stock Assessment Committee. The final fishing plans adopted by Fisheries Management will be based not only on biological considerations, but also economic and social, enforcement, and other factors.

Results contained in this report were presented to the Herring Stock Assessment Committee in September of 1985.

ACKNOWLEDGMENTS

This document not only represents the efforts of the Population Dynamics Program but numerous other members of the departmental staff play key roles in collection and processing of data. Herring ages were determined by Margaret Burke and Karen Charles of the Pacific Biological Station Ageing Unit. Lorena Rosenfeld processed the catch, sample, and spawn data and maintained the pertinent data bases. Also, Field Services personnel and contractors contribute to the sampling effort.

1. INTRODUCTION

1.1 GENERAL

Forecasting the potential catch that can be removed from herring stocks requires an assessment of the status and determination of the factors which affect stock dynamics. Traditionally, yield models have assumed equilibrium conditions implying no changes in age structure, growth, or mortality over time. However, herring are strongly affected by changes in environmental conditions thus making equilibrium models unattractive. The methods we use try to estimate current stock conditions on the basis of which potential catches are recommended that will not have deleterious effects on the stocks.

In this report we present two methods to assess herring stock conditions: (1) escapement method (Schweigert and Stocker 1986), and (2) age-structured model analysis (Fournier and Archibald 1982). Both methods use a 35-year time series of catch and spawn deposition data; the second method also uses age composition data.

In addition to the two stock assessment methods we present preliminary analysis on determination of CUTOFF levels in this report. CUTOFF levels are minimum stock levels below which fisheries should cease and they are related to the estimated unfished equilibrium biomass of the stock. CUTOFF levels have been incorporated into the forecasting procedure to determine potential catch for each stock grouping.

1.2 DATA BASE

The primary data used for these stock assessment methods are spawn survey data, commercial catch landing data, and age composition data from biological samples of commercial catches or from pre-fishery charter and research cruises. These data are available on computer files in a consistent record for the period 1950 to 1985. This time span includes the reduction fishery period to 1968 and the subsequent "roe" fishery period starting in the early 1970s.

Of the three sets of information the spawn data contain the largest measurement errors. We feel that the quality of spawn surveys has improved greatly over the 35-year span of these observations. This improvement is a result of increased numbers of people and vessels being involved in spawn surveys, increased attention to data measurements, increased coverage of subtidal spawnings, and increased research on estimating egg deposition from spawn observations. The only consistent observations made during the 35 years of spawn surveys are the length, the width, and a measure of intensity of spawnings. The escapement method estimates absolute egg numbers from these observations and includes a width conversion to adjust for the inability to

survey subtidal spawns adequately. The age-structured model uses a spawn index which sums lengths times standardized widths and intensities.

Catch information was obtained from landing slip data. Both methods use the landing slip data summed by season (seasons run from July 1 to June 30). The 1984/85 catch figures are based on hailed estimates because sales slip data were not available for timely analysis. The sales slips record catch in tonnes. Numbers of fish in the catch, for use in the age-structured model, were calculated using the average fish weight from catch samples for the season.

Age structure data, obtained from biological samples, are used in the age-structured model. The information from catch samples are used for years when there were commercial fisheries. For years with no fisheries, or when catch samples do not appear to be representative, pre-fishery and research samples are also used to obtain age compositions. Additional information obtained from the biological sampling data base and used in the age-structured model includes data on age specific fecundities and average weights at age.

1.3 STOCK CONSIDERATIONS

A revised stock concept which attempts to separate the major migratory herring stocks from the more localized or non-migratory herring stocks is used for this year's stock assessments. The new operational scheme follows closely the one adopted by the PBS Herring Section at a meeting evaluating recent, and historic data of spawn distribution, spawn timing, tagging, size-at-age, and age-composition. The differences result from the inability to allocate reduction catches to certain stock groupings, and an insufficient time series of catch-at-age data to allow independent analysis for some groupings. Age-structured model reconstructions and forecasts are based on these new stock groupings. Escapement method results are available by section (Fig. 1.1 and Fig. 1.2) and management unit (Fig. 1.3) as well as by the current operational framework.

For the Queen Charlotte Islands the areas included in our analyses are sections 21, 24, and 25 (Skincuttle to Selwyn Inlet). Major reduction fisheries took place in Skidegate Inlet but size at age indicates these fish are generally smaller than in the Skincuttle-Selwyn area, and were therefore not included in the analysis.

For the Prince Rupert District no change has been made to our stock concept; this area includes all of sections 31 to 54. In the central coast we have attempted to separate the major migratory stock from local or non-migratory stocks. In our analyses we include sections 67, 72-76, 85, and parts of section 71 (East Higgins Pass and Spillar Channel). A significant proportion of the reduction fishery catches in the central coast came from areas not included in our current analysis. The average catch between 1950 and 1966 for the "migratory" component of the stock was 21.3 thousand tonnes and for the "local" component 10.9 thousand tonnes.

Separation of the Strait of Georgia and Johnstone Strait into consistent stock groupings is more problematic than for other areas of the coast. The major winter reduction fisheries were located in section 132 (Deepwater Bay) and in the south throughout Areas 17, 18, and 19. Only small summer fisheries occured in areas 14 to 16. Fisheries in Area 12 also occurred predominantly in the summer. However, the greatest spawnings in these areas have been in areas 14 to 16, and it is currently felt that these fish are a mixture from both the migratory stocks moving through the northern and the southern Gulf. For the purpose of present analysis we have included sections 132, 141 to 165, and 172 in the northern Gulf stock, whereas Areas 17S, 18, and 19 are included in the southern stock grouping.

For the west coast of Vancouver Island two stock groupings are used for the present analyses. The southern west coast Vancouver Island group includes Areas 23 and 24, and the northern group includes Areas 25 to 27. While there is some evidence suggesting Area 25S is part of the Barkley/Clayoquot Sound stock, most of the reduction catch in Area 25 is coded as location unknown so that catch for this area can not be assigned to the correct area.

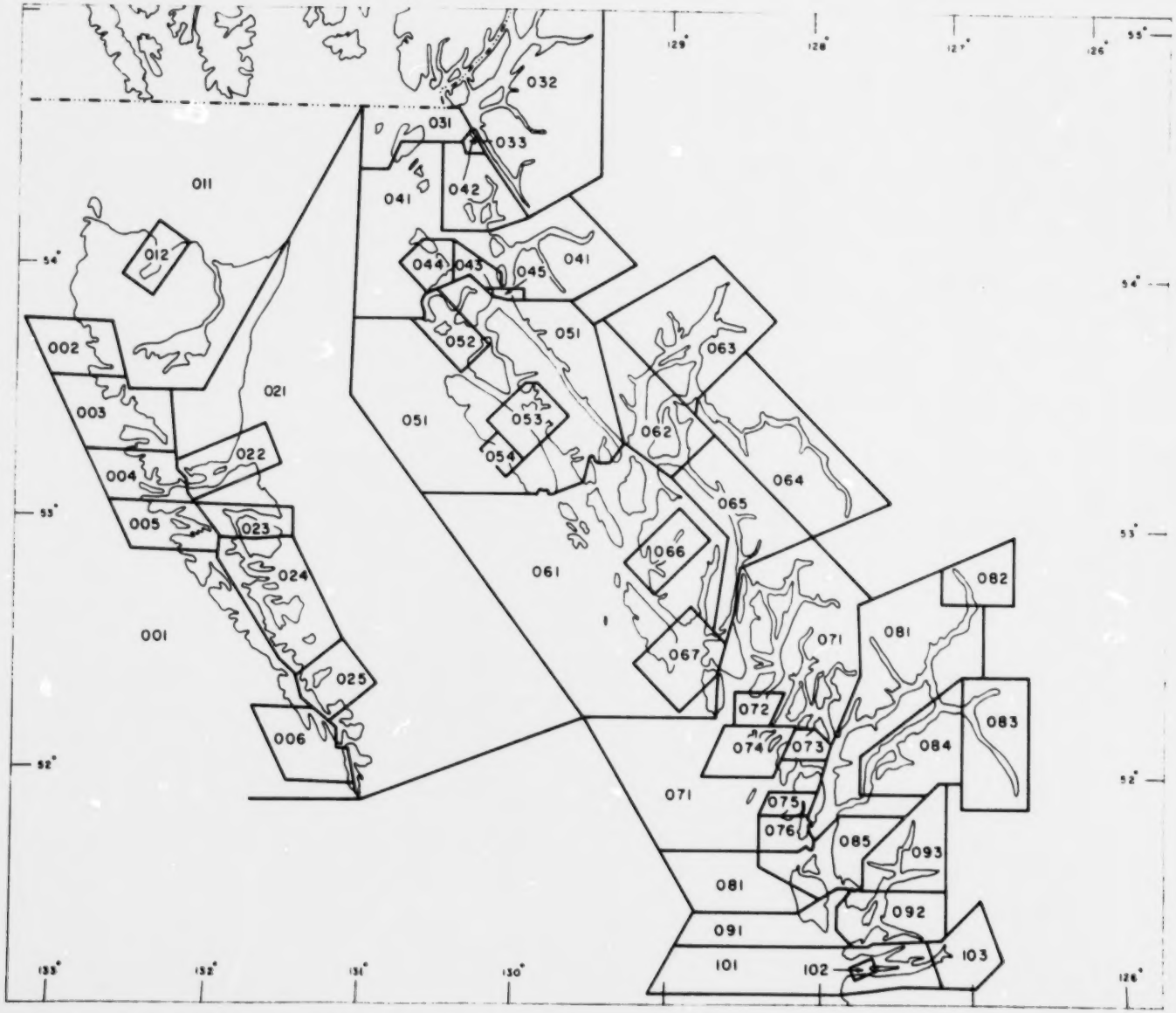

Fig. 1.1. Herring sections in northern B.C.

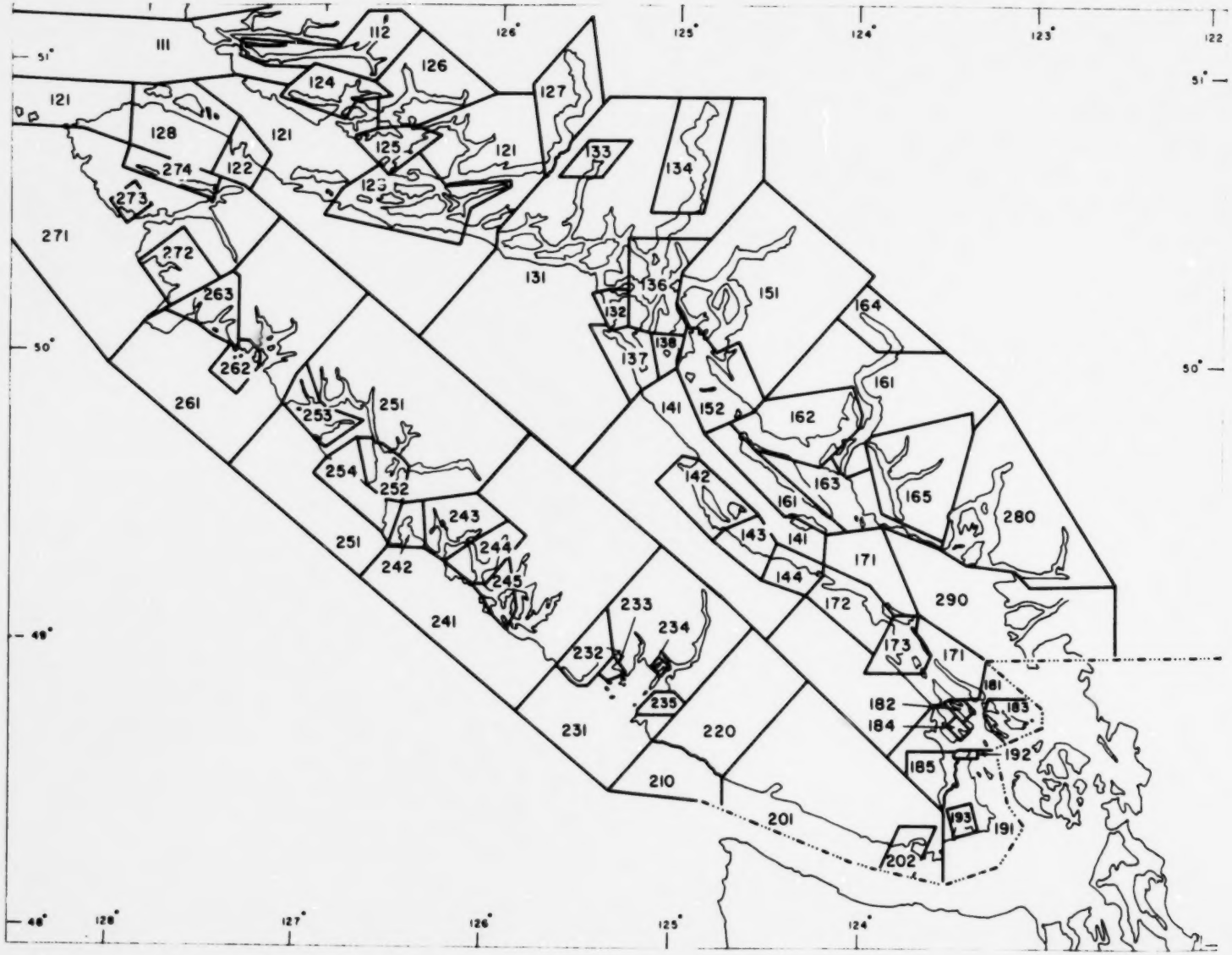

Fig. 1.2. Herring sections in southern B.C.

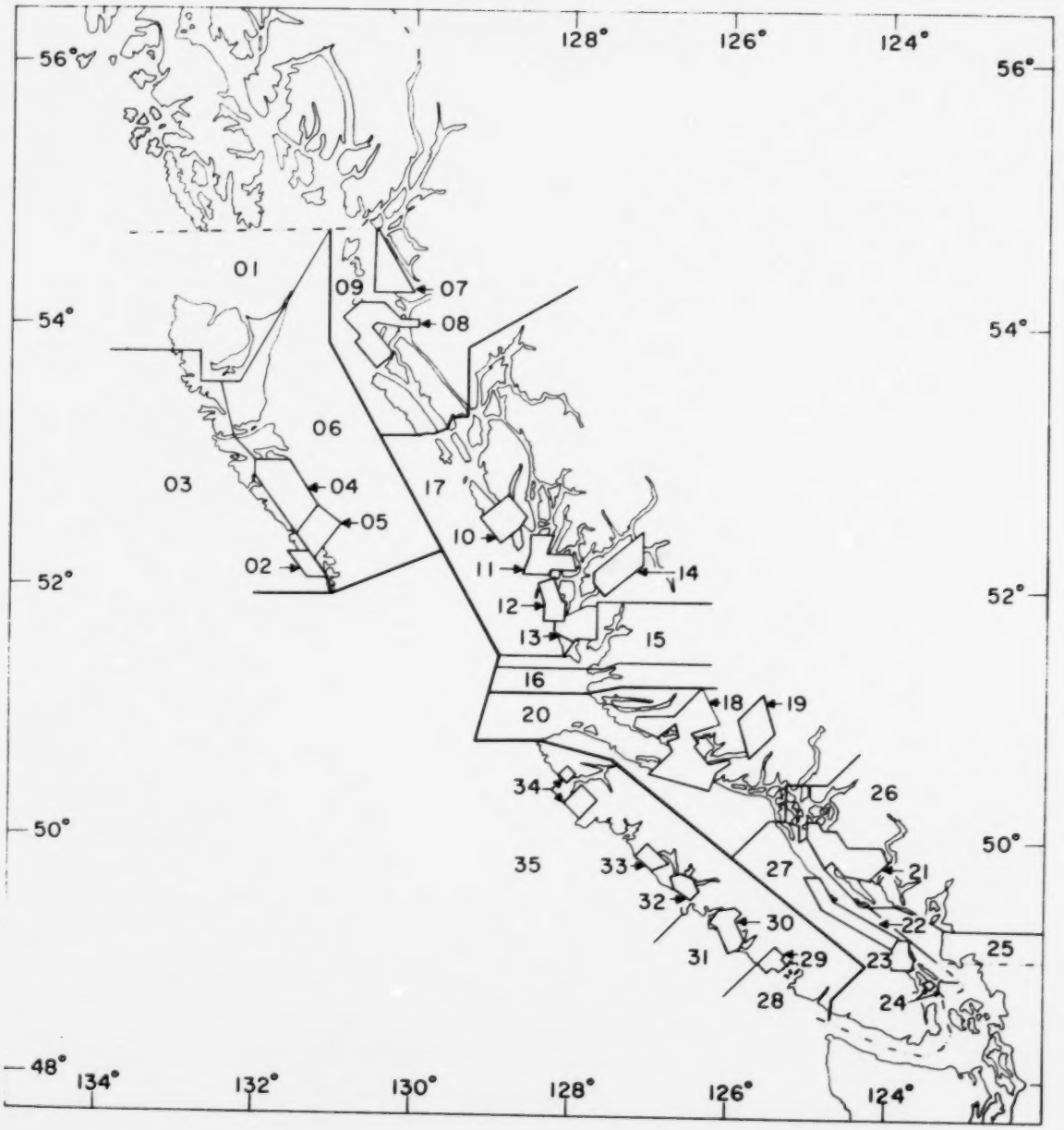

Fig. 1.3. Management units for British Columbia herring roe fisheries.

2. ESCAPEMENT METHOD

2.1 INTRODUCTION

The escapement method is a new analytical procedure developed for assessing and forecasting herring stock abundance. It was first used for the 1984 stock assessments and 1985 forecasts. It is similar in many regards to the Hourston method (Hourston 1981) which it has replaced. It differs in that it does not presently incorporate age structure information and it does not use the egg survival factor to account for egg mortality. Instead, it adjusts upward the fishery officer estimates of spawn widths (Schweigert and Stocker 1986).

The stock assessment may be done at any level of geographic amalgamation from the section level, to management units, to divisions (see Hourston and Hamer 1979, for a description of geographic areas). This year we have also adopted stock assessment regions which represent the major migratory portions of the spawning stocks in each division. To maintain continuity with previous assessments stock estimates are presented at the management unit and division level (Table 2.1) as well as for the new groups (Table 2.3).

The analysis has two components, the assessment of the spawning stock in a given year and the forecast of runs in the following year. The spawning stock abundance is dependent entirely on the estimates of egg deposition from fishery officer spawn surveys. Forecasts of runs to management units or divisions have two components. First, the estimate of adults (repeat spawners) obtained from applying an average survival rate to the previous year's spawning escapement. Second, the estimate of production which is an average estimated for the stock from previous years.

2.2 METHODS

The methodology we have used for the 1985 assessment and 1986 forecasts is similar to that presented by Schweigert and Stocker (1986). The spawn data collected by fishery officers (F.O.) includes length and width of spawn, and layers of eggs on various spawn substrates. The spawning stock size in any given area in a year is estimated from the fishery officer estimate of area of deposition and spawning intensity. The reported length times an adjusted width is used to estimate a total area of spawn deposition. The estimates of the average number of layers of eggs for each spawn are then converted to egg density from an equation which relates the mean egg density in a spawn from counted samples to the F.O. estimates of average layers. The mean egg density times the area estimates the total number of eggs deposited in each individual spawn. Egg depositions within geographic areas are then aggregated to estimate the total spawning escapement at the requisite scale for management. Tonnes of spawners are approximately given by the total egg deposition divided by 200 eggs^{-1} g of female weight. The spawning escapement plus the total catch provides an estimate of the total pre-fishery spawning population for each area in each year.

The forecast of the anticipated spawning run in year t+1 is estimated from the spawning escapement in year t times an estimate of the average survival rate (.64) for one year (Beverton 1963) plus an estimate of stock production. Production was estimated separately as the average over the time series from 1951 to 1985 and for the roe fishery period, 1970-1985, respectively. Forecasts assuming good and poor production were determined by taking plus or minus one standard deviation of the average value.

The formulae used for adjusting fishery officer spawn widths and estimating mean egg density differ slightly from the formulae in Schweigert and Stocker (1986) as more data points became available through the 1985 diver spawn surveys. The equation and parameter estimates for the width adjustment is given by:

$$\text{Adjusted width} = \exp\left(0.375 \log_e (\text{observed width}) + 3.401 \bar{x} \text{ area effect}\right)$$

where area effect for QCI = - 0.159
North and Central Coast = -0.278
Strait of Georgia = -0.002
West Coast Vancouver Is. = 0.000

No width adjustment was made to Johnstone Strait spawns this year. The equation to estimate egg density from the fishery officer layer estimate is given by:

$$\text{Eggs/m}^2 = 75.861 + 105.321 \cdot \text{average layers.}$$

Because these equations are slightly changed from those used in last year's assessment the stock size estimates are slightly different from those found in the 1985 stock assessment document (Haist et al. 1985). Similarly, these values may change slightly next year as additional data is collected from other areas where diving spawn surveys are to be conducted during the spring of 1986.

2.3 STATUS OF THE STOCKS

Estimates of spawners and hailed roe catches in 1985 and of total pre-fishery abundance for the period 1970-85 for all management units and divisions are shown in Table 2.1. The 1985 pre-fishery biomass for the Queen Charlotte Islands was estimated at 24,700 tonnes. This represents a 13 percent decrease from the 1984 pre-fishery biomass. All management units but Louscoone show a decrease in abundance over the previous year. The migratory stocks in this area were estimated at 19,400 tonnes in 1985 which represents a 9 percent decrease from 1984. For the north coast division the estimated pre-fishery biomass was 30,300 tonnes which is a 49 percent increase over the previous year. North coast stocks appear to have recovered to or above levels observed in the early and mid 1970s. The central coast pre-fishery biomass for 1985 was estimated as 20,800 tonnes which is a 28 percent decrease from

the 1984 level and indicates that stocks have declined to levels near those following the crash of the late 1960s. Kitasu Bay appears to be at a historically high level while Queens Sound, and Rivers Inlet are at historical low levels. Stocks in the other areas of the central coast are near average values for the period of the roe fishery but are on a downward trend. The migratory stocks in the central coast were estimated at 17,300 tonnes in 1985 or a 15 percent decrease from the previous season. Generally, only the north coast stock appears to be in good condition relative to historical roe fishery levels.

The estimated pre-fishery biomass in the Johnstone Strait division in 1985 was 800 tonnes. This is a decrease of 31 percent from 1984 and is part of a continuing decrease begun in the mid 1970s. In the Strait of Georgia division the 1985 pre-fishery biomass estimate of 19,200 tonnes represents a decrease of 44 percent from the previous year and leaves the stocks in this area at levels reached during the fishery closure at the end of the reduction period. Stocks in the Ganges-Plumper area have all but disappeared while stocks in the Yellow Point area are near average levels for the roe fishery period. Nanaimo-Comox stocks are about one third of historical levels while Powell River stocks are about average. Two migratory stock components are identified in this area. The northern Gulf was estimated at 14,100 tonnes in 1985 or a 31 percent decline from 1984. Similarly, the southern component was estimated at 5,300 tonnes in 1985, a 62 percent decrease from 1984. The 1985 pre-fishery biomass for the west coast of Vancouver Island was 16,200 tonnes which represents a 20 percent decline from 1984 levels. Stocks in all areas have demonstrated a steady decline since about 1980 and are at historical low levels for the roe fishery period, 1970-85. There are also two migratory stock components in this area. The southern group in areas 23 and 24 was estimated at 14,900 tonnes in 1985, down 16 percent from 1984. The northern component, statistical areas 25-27, was estimated at 1,301 tonnes, down 49 percent from the previous season. The downward trend in all south coast stocks is still evident this year.

2.4 FORECASTS

Forecasts of 1986 runs to management units and divisions, and migratory components thereof, assuming poor, average, and good production are shown in Tables 2.2 and 2.3. The production estimate reflects a net change in biomass which results from growth, recruitment, and migration.

Assuming average production for the roe fishery period, 1970-85, the forecast stock biomass in 1986 is expected to be 26,500 t for the Queen Charlotte Islands, 23,500 t for the north coast, and 25,100 t for the central coast (Table 2.2). Taken together this implies a total pre-fishery biomass of 75,100 t for the northern district. However, since stocks in some of the northern areas are showing downward trends it is possible that lower than average production will occur in some of these areas. The migratory component of the Queen Charlotte Islands stock is forecast at 17,100 t with average production. Similarly, the migratory portion of the north coast stock is 23,500 t with average production. Stocks in this area are on an upward trend

so that it is possible that the production to this area in 1986 may be higher than forecast. Finally, the central coast migratory stock is forecast at 19,200 with average production. However, stocks in this area are on a downward trend so that the low production forecast of 12,800 t is anticipated. This yields a combined stock forecast of 53,400 t for the northern stocks (Table 2.2, 2.3).

The forecast biomass assuming average production is 3,200 t for Johnstone Strait, 32,200 t for the Strait of Georgia, and 32,600 t for the west coast of Vancouver Island implying a total prefishery biomass of 68,000 t for the entire south coast. However, since these areas have all undergone a long term decline to the lowest levels recorded during the history of the roe fishery below average production is anticipated for most stock components (Table 2.2). The migratory stocks in the Gulf are forecast at 10,300 t in the northern area (14-16) assuming low production. The southern component in this area, assuming low production, was forecast at 4,300 tonnes. The low production forecasts for the northern and southern components of the stocks on the west coast of Vancouver Island are 1,600 and 12,200 tonnes, respectively. The total forecast run for poor production to the south coast is 28,300 tonnes. The low stock levels in these areas may preclude roe fisheries.

Table 2.1. Catch (tonnes) and spawners (tonnes) for 1985, and total abundance (tonnes) for 1970 to 1985 by management unit for the Queen Charlotte Islands division.

Year	Management Unit						
	North Coast 01	Louscoone 02	Other Area2W 03	Laskeek Bay 04	Skincuttle 05	Other Area2E 06	Total QCI Division
70	54.	351.	946.	25.	2506.	4725.	8606.
71	0.	1412.	838.	0.	4493.	8087.	14829.
72	13.	2619.	1841.	127.	3547.	10023.	18171.
73	0.	3643.	2682.	0.	4001.	9285.	19610.
74	3176.	3017.	3069.	0.	6640.	6862.	22763.
75	683.	5183.	2259.	0.	7387.	5753.	21266.
76	2957.	7174.	1436.	422.	14882.	6343.	33214.
77	3046.	3927.	2238.	14.	17027.	4963.	31216.
78	4760.	2986.	2570.	111.	16295.	4706.	31428.
79	1494.	746.	2143.	610.	12014.	3966.	20973.
80	1998.	2102.	3774.	1313.	20316.	31.	29534.
81	1503.	678.	4691.	7254.	16771.	1896.	32794.
82	2264.	1340.	9442.	4576.	14429.	1038.	33089.
83	146.	846.	10407.	8260.	10629.	1414.	31702.
84	37.	437.	4028.	6626.	14658.	2760.	28545.
85	1208.	637.	2495.	2404.	17009.	940.	24694.
	1985 Catch						
Seine	0.	0.	0.	0.	4846.	0.	4846.
Gillnet	0.	0.	0.	0.	1487.	0.	1487.
Spawners	0.	637.	2495.	2404.	10676.	940.	17152.

Table 2.1 (cont'd) Catch (tonnes) and spawners (tonnes) for 1985, and total abundance (tonnes) for 1970 to 1985 by management unit for North Coast division.

	Management Unit			
Year	Chatham Sound 07	Porcher Island 08	Other North 09	Total NC Division
70	5276.	2194.	863.	8333.
71	4785.	4677.	579.	10041.
72	6568.	4180.	1077.	11824.
73	5753.	3331.	117.	9200.
74	4778.	3874.	256.	8908.
75	3329.	4878.	103.	8309.
76	6235.	8023.	304.	14566.
77	9050.	7062.	565.	16677.
78	3966.	5600.	2816.	12383.
79	5949.	6434.	1660.	14044.
80	3706.	10136.	591.	14433.
81	4516.	8894.	1486.	14896.
82	6451.	3510.	1799.	11760.
83	6040.	9889.	546.	16475.
84	10494.	9304.	1034.	20832.
85	17130.	12826.	366.	30322.
		1985	Catch	
Seine	254.	3018.	0.	3272.
Gillnet	3481.	0.	0.	3481.
Spawners	13396.	9808.	366.	23569.

Table 2.1 (cont'd) Catch (tonnes) and spawners (tonnes) for 1985, and total abundance (tonnes) for 1970 to 1985 by management unit for Central Coast division.

Year	Management Unit: Kitasu Bay 10	Milbanke Sound 11	Queen's Sound 12	Kwakshua Channel 13	Burke Channel 14	River's Inlet 15	Smith Inlet 16	Other Central 17	Central Division
70	8560.	1448.	2312.	1216.	55.	3540.	1512.	6787.	25430.
71	2305.	3391.	1908.	0.	2036.	3496.	2620.	8013.	23770.
72	1128.	4349.	5917.	1689.	3494.	3812.	2159.	5174.	27722.
73	7006.	8642.	3959.	2702.	6990.	5853.	1533.	4092.	40777.
74	3693.	8234.	4163.	2942.	5733.	2788.	864.	2888.	31304.
75	5814.	5876.	3551.	4342.	4625.	4944.	930.	3049.	33130.
76	3766.	14479.	6636.	2814.	5961.	2601.	750.	5683.	42690.
77	4137.	14068.	7404.	967.	5716.	4193.	456.	906.	37846.
78	4655.	11844.	5341.	1843.	2563.	2073.	1250.	648.	30217.
79	2516.	2005.	1249.	1678.	2504.	352.	272.	2093.	12667.
80	5998.	8317.	2916.	2960.	0.	1157.	1538.	1519.	24405.
81	7690.	12421.	958.	2180.	1604.	565.	622.	1040.	27080.
82	6217.	19437.	1240.	1689.	0.	874.	1825.	860.	32142.
83	10249.	16891.	480.	2281.	1529.	136.	662.	2170.	34397.
84	8175.	9977.	164.	1960.	3512.	462.	1164.	3594.	29008.
85	10300.	5347.	43.	1584.	581.	574.	652.	1705.	20785.
1985 Catch									
Seine	2956.	0.	0.	0.	0.	0.	0.	0.	2956.
Gillnet	1359.	817.	0.	0.	0.	0.	0.	0.	2214.
Spawners	5985.	4529.	43.	1546.	581.	574.	652.	1705.	15615.

Table 2.1 (cont'd) Catch (tonnes) and spawners (tonnes) for 1985, and total abundance (tonnes) for 1970 to 1985 by management unit for the Johnstone Strait division.

Year	Management Unit: Upper Johnstone 18	Knight Inlet 19	Other Johnstone 20	Total JS Division
70	813.	219.	2063.	3905.
71	1042.	54.	1625.	2721.
72	2416.	886.	4683.	7985.
73	2287.	3479.	8598.	14364.
74	1935.	3446.	1193.	6574.
75	2908.	3180.	1076.	7164.
76	2022.	1938.	1345.	5305.
77	779.	1339.	1498.	3616.
78	811.	509.	3825.	5144.
79	156.	41.	2512.	2709.
80	695.	242.	1815.	2753.
81	651.	198.	1353.	2202.
82	168.	466.	349.	982.
83	116.	197.	372.	685.
84	507.	384.	286.	1176.
85	97.	417.	297.	811.
		1985 Catch		
Seine	0.	0.	246.	246.
Gillnet	0.	0.	0.	0.
Spawners	97.	417.	51.	565.

Table 2.1 (cont'd) Catch (tonnes) and spawners (tonnes) for 1985, and total abundance (tonnes) for 1970 to 1985 by management unit for the Strait of Georgia division.

	Management Unit							
Year	Powell River 21	Nanaimo Comox 22	Yellow Point 23	Ganges Plumper 24	Area 29 25	Other Gulf 26	Other Van. Is. 27	Total GS Division
70	9287.	8927.	1201.	7708.	0.	2236.	888.	30247.
71	7260.	15221.	1198.	6464.	0.	1069.	816.	32028.
72	7829.	8160.	623.	5401.	0.	853.	3047.	25925.
73	7009.	11317.	1970.	5391.	0.	466.	535.	26688.
74	1963.	24709.	7316.	6320.	0.	318.	342.	40967.
75	5826.	33913.	5810.	8405.	0.	946.	506.	55406.
76	5091.	35862.	7199.	3910.	0.	971.	1336.	54369.
77	4783.	48209.	3086.	6468.	0.	408.	1034.	63989.
78	3824.	56607.	8351.	3375.	0.	57.	9651.	81864.
79	14340.	38704.	11012.	1986.	0.	112.	11478.	77633.
80	3900.	46291.	8043.	1602.	0.	934.	1447.	62216.
81	4653.	27420.	11248.	2362.	0.	165.	2694.	48542.
82	6318.	47731.	8296.	727.	0.	276.	12359.	75707.
83	7356.	36269.	11729.	75.	0.	55.	4414.	59898.
84	6686.	13457.	13526.	0.	0.	74.	447.	34190.
85	2370.	11516.	4319.	1021.	0.	0.	0.	19227.
				1985 Catch				
Seine	0.	2645.	609.	0.	0.	0.	0.	3254.
Gillnet	0.	3475.	0.	0.	0.	0.	0.	3475.
Spawners	2370.	5397.	3710.	1021.	0.	0.	0.	12498.

Table 2.1 (cont'd) Catch (tonnes) and spawners (tonnes) for 1985, and total abundance (tonnes) for 1970 to 1985 by management unit for the West Coast of Vancouver Island division.

Year	Management Unit								
	West Barkley 28	Other Area23 29	South Clayoquot 30	Other Area24 31	Nootka Sound 32	Nuchatlitz Inlet 33	Quatsino Sound 34	Other Upper WC 35	Total WCVI
70	8120.	155.	3658.	2970.	1486.	1691.	0.	933.	19013.
71	8316.	384.	6172.	459.	3334.	1256.	0.	1546.	21468.
72	7104.	60.	7401.	4488.	1214.	10365.	0.	2710.	33342.
73	4370.	198.	1817.	9517.	3141.	11132.	0.	1764.	31939.
74	8992.	0.	8249.	1702.	3839.	10964.	0.	976.	34722.
75	15357.	639.	10475.	11748.	7047.	8796.	0.	875.	54938.
76	28838.	4203.	12242.	15099.	1686.	7891.	0.	560.	70519.
77	33406.	778.	15765.	4045.	770.	6714.	0.	373.	61850.
78	14939.	2395.	12953.	2258.	675.	9050.	0.	417.	42686.
79	20064.	565.	15056.	1412.	11414.	11304.	0.	0.	59815.
80	10412.	0.	14918.	1844.	0.	7637.	0.	0.	34811.
81	12461.	2.	10989.	2834.	4221.	5625.	0.	0.	36132.
82	9465.	2.	3189.	529.	0.	8081.	0.	0.	21266.
83	14090.	271.	1339.	757.	0.	6097.	0.	0.	22554.
84	5423.	5906.	6359.	111.	110.	2422.	0.	0.	20331.
85	8197.	1824.	3851.	994.	40.	1261.	0.	0.	16168.
	1985 Catch								
Seine	0.	0.	0.	177.	0.	0.	0.	0.	177.
Gillnet	0.	0.	0.	0.	0.	0.	0.	0.	0.
Spawners	8197.	1824.	3851.	818.	40.	1261.	0.	0.	15992.

Table 2.2. Forecast of the 1986 runs in tonnes of fish by management unit and division for poor, average and good production.

Division and Management unit	Adults	Production -1Std	Production Avg.	Production +1Std	Forecast Run Poor	Forecast Run Avg.	Forecast Run Good
Queen Charlotte Is.							
North Coast	773	-858	621	2100	-84	1394	2873
Louscoone Inlet	407	-33	1348	2729	375	1755	3136
Other Area 2W	1597	-368	1673	3714	1228	3270	5311
Laskeek Bay	1539	-559	2154	4867	979	3693	6406
Skincuttle Inlet	6833	2606	7426	12246	9438	14259	19079
Other Area 2E	602	27	2267	4507	629	2869	5109
All QCI	11750	9668	14703	19738	21418	26453	31489
North Coast							
Catham Sound	8574	825	3697	6569	9398	12271	15143
Porcher Island	6277	1436	3980	6524	7713	10257	12801
Other North Coast	234	-31	736	1503	203	970	1737
All NC	15084	4463	8413	12363	19547	23497	27448
Central Coast							
Kitasu Bay	3830	124	2767	5410	3954	6597	9240
Milbanke Sound	2899	2033	5978	9923	4932	8877	12822
Queens Sound	27	-362	1796	3954	-335	1823	3982
Kwakshua Channel	990	56	1039	2022	1046	2029	3012
Burke Channel	372	-200	1641	3482	172	2013	3854
Rivers Inlet	367	-673	848	2369	-305	1215	2736
Smith Inlet	417	-258	454	1166	159	871	1583
Other Central	1091	-537	1072	2681	554	2163	3772
All Central	9994	7703	15113	22523	17697	25107	32517
Johnstone Strait							
Upper Johnstone	62	-132	689	1510	-69	751	1572
Knight Inlet	266	-362	483	1328	-96	749	1594
Other Johnstone	33	-466	1649	3764	-433	1682	3797
All JS	362	-466	2821	6108	-104	3183	6469

Table 2.2. (cont'd)

Division and Management unit	Adults	Production -1Std	Avg.	+1Std	Forecast Run Poor	Avg.	Good
Strait of Georgia							
Powell River	1517	-1421	2284	5989	96	3801	7506
Nanaimo-Comox	3454	2457	14662	26867	5912	18116	30321
Yellow Point	2375	-567	2840	6247	1808	5215	8621
Ganges-Plumper	654	-346	1697	3740	308	2351	4394
Other Str Georgia	0	-240	152	544	-240	152	543
Other Vancouver Is	0	-1633	2923	7479	-1632	2923	7479
All GS	7999	8704	24192	39680	16703	32191	47679
West Coast of Vancouver Island							
West Barkley	5246	-90	8147	16384	5156	13393	21630
Other Area 23	1168	-1339	716	2771	-172	1884	3939
South Clayoquot	2464	-48	4314	8676	2416	6778	11140
Other Area 24	523	-1393	3039	7471	-870	3562	7994
Nootka Inlet	25	-1526	2160	5846	-1501	2185	5872
Nuchatlitz Inlet	807	1423	4653	7883	2231	5460	8690
Quatsino Sound	0	-248	386	1020	-248	386	1020
All WCVI	10234	6394	22377	38360	16628	32611	48595

Table 2.3. Estimates of the 1985 pre-fishery biomass and forecasts of the 1986 spawning run for the six management divisions and the entire B.C. coast with recruitments estimated for the roe fishery period, 1970-85 and for the combined roe-reduction fishery period, 1951-85. Estimates of pre-fishery spawning biomass are also presented for the major migratory components of each management division.

Management Areas	Pre-fishery Biomass, 1985	Forecasts of 1986 spawning biomass					
		Average Production(1970-85)			Average Production(1951-85)		
		-1 Std	Avg.	+1 Std	-1 Std	Avg.	+1 Std
Queen Charlotte Is.	24694	21418	26453	31489	13379	28548	43716
Sections 21,24,25	19414	12188	17128	22068	4908	19146	33385
North Coast	30322	19547	23497	27448	18079	31539	44999
Central Coast	20785	17697	25107	32517	19138	34564	49991
Sections 67,72-76,85	17273	12823	19248	25673	13351	24250	35149
Johnstone Strait	811	0	3183	6469	135	11568	23000
Georgia Strait	19227	16703	32191	47679	21629	43491	65353
Area 14-16,Sect.132,172	14133	10293	22954	35616	13354	26533	39711
Area 18-19,Sect.171,173	5340	4295	9798	15300	6091	22124	38157
West Coast Vancouver Is.	16168	16628	32611	48595	19377	36876	54376
Area 23,24	14867	12180	25562	38944	14980	27513	40047
Area 25-27	1301	1574	7050	12525	92	9363	18634
B.C. Coast	112007	113435	143043	172651	117878	186586	255294

3. AGE-STRUCTURED MODEL

3.1 INTRODUCTION

An age-structured model has been used to assess B.C. herring stocks since 1982 (Stocker et al. 1983); this model is a modified version of the one described in Fournier and Archibald (1982). The major differences in the version used to assess B.C. herring stocks are the incorporation of spawn survey data and the reparameterization of the catch equations to separate gillnet and seine fisheries. The model includes realistic assumptions about the form of both measurement and process errors. A maximum likelihood method is used to simultaneously esimate all model parameters.

The use of the age-structured model to assess B.C. herring stocks is an ongoing process of refining the model so that it is more consistent with the life history of B.C. herring and with the fisheries being analyzed. For the 1985 stock assessments the model is essentially the same as described in Haist et al. (1985). However, because of inconsistencies between model results and independent assessments of south coast stock trends in recent years two alternate hypotheses were incorporated and evaluated in the model. These additional hypotheses are density dependent natural mortality and high weighting on spawn relationships for recent years. A new spawn index (Hay and Kronlund, 1985) is also evaluated in this analysis.

3.2 METHODS

The general age-structured model used in this analysis has been described in detail elsewhere (Fournier and Archibald 1982); the inclusion of spawn data in the model is also documented (Stocker et al. 1985). The following model description deals primarily with aspects of the model which are specific to B.C. herring stock assessments.

Parameters which are estimated by the model include the instantaneous rates of fishing (F) and natural (M) mortalities as well as the numbers of fish at age j in period r of year i (N_{ijr}) for each year of the data series. The parameters are estimated by minimizing an objective function which has terms for all components of the model. Simplified versions (variance estimates and constants are not included) of the major components of the objective function are:

- the log likelihood function for the parameters P_{ijr} and C_{ir}

  $\Sigma_{ijr} S_{ijr} \log P_{ijr} - w\Sigma_{ir} (\log O_{ir} - \log C_{ir})^2$

- the contribution from the true spawn - recruitment relationship (a Ricker type parameterization is used)

$$- w\sum_i (\log (N_{i+1,1,1}) - \log\alpha - \log (TS_i) + \beta TS_i)^2$$

- the contribution from the true spawn-escapement relationship

$$-w\sum_i (\log (\sum_j f_j N_{ij1}) - QSP - \log (TS_i))^2$$

- the contribution from the true spawn - observed spawn relationship

$$- w\sum_i (\log(TS_i) - \log(OS_i))^2$$

where S_{ijr} = the number of fish observed to be of age j in period r of year i

P_{ijr} = the actual percentage of fish of age j in the catch in period r of year i

O_{ir} = estimated number of fish caught during period r of year i

C_{ir} = actual number of fish caught during period r of year i

f_j = relative fecundity of fish of age j

TS_i = true spawn in year i

QSP = true spawn - escapement coefficient

OS_i = observed spawn in year i

The penalty weights (w) are assigned by the user and reflect his intuition about the relative accuracy of the data. The spawn related penalty weights used in the baseline computer runs of this analysis are:

20 for the true spawn - escapement relationship

10 for the true spawn - observed spawn relationship

5 for the true spawn - recruitment relationship

These penalty weights reflect our belief that herring do not follow a very strong stock - recruitment relationship , and our mistrust of the earlier spawn index data. By placing the highest weight on the true spawn-escapement relationship the true spawn estimates should follow the escapement estimates from the age structure data to a relatively greater degree.

A second set of computer analyses were conducted for all stock groupings using a different set of spawn penalty weights for the period 1981 to 1985. These are:

500 for the true spawn - escapement relationship

500 for the true spawn - observed spawn relationship

5 for the true spawn - recruitment relationship

The higher penalty weights on the first two relationships should force the model to follow the trends in the spawn index data for the last five years to a greater degree.

In most cases the total sample sizes ($\sum_j S_{ijr}$) were rescaled to 400 for the seine fishery data, as discussed in Fournier and Archibald (1982). The exceptions to this are for the years 1966 to 1970 where sample sizes were rescaled to 25. During those years individual fish had not been aged and age compositions had been determined from age-length keys. The effect of rescaling sample sizes to 25 for these years is that the model can deviate to a greater extent from the observed age structure of the catch. Sample sizes were scaled to 100 for the gillnet fishing period. The last four age classes (ages 7 to 10) are grouped together.

For the Strait of Georgia and west coast of Vancouver Island stock groupings the age structure used in the model for seine gear was the combined charter and seine roe fishery samples (in other areas only fishery samples are used). The rationale for this is that there appears to be a spatial separation of fish by age. For example, samples from Nanoose Bay (section 172) generally contain a much higher proportion of juvenile fish than do samples from other areas of the Strait of Georgia. Because seine roe fisheries occured at different locations within the Gulf, fishery samples alone will represent different components of the stock over the time period. By using the pre-fishery samples in addition to the fishery samples the age-structure should be more representative of the entire stock.

Instantaneous fishing (F_{ijr}) and natural (M_r) mortality rates are incorporated into the model through the catch equations :

$$P_{ijr}C_{ir}=F_{ijr}/(F_{ijr}+M_r)(1-\exp(-F_{ijr}-M_r))\ N_{ijr}$$

The following two-factor model was used to reparameterize fishing mortality

$$\log F_{ijr} = a_{ir} + b_{jr} \quad , \tag{3.1}$$

where a_{ir} represents the general level of fishing mortality due to the fishery in period r of year i, and b_{jr} represents the relative level of fishing vulnerability of age class j in period r. Two fishing periods were used in this analysis. The first period uses catch-at-age information from seine gear. This includes the reduction (primarily winter) fisheries prior to 1970, and the food/bait (winter) and seine roe (spawning) fisheries since 1970. The second period uses catch-at-age information from gillnet gear and is represented only by roe fisheries since 1971. Gillnet roe fisheries generally occur after the seine roe fisheries in an area.

The proportion of fish at age two is highly variable between years of the reduction fisheries. This variability does not relate to differences in cohort size, but is likely the result of concentrated fishing on immature schools. To allow for deviations in fishing mortality for two-yr-olds during these years (i=1 to i=20) an additional term is added to equation 3.1 such that:

$$\log (F_{i,2,1}) = a_{i,1} + b_{2,1} + D_i ,$$

and the term

$$- \rho \Sigma_i \ D_i^2$$

is added to the objective function; ρ is a penalty weight which is set to 2 for all computer runs in this analysis.

To incorporate density dependent natural mortality into the model relative biomass is estimated as

$$R_i = (B_i - \bar{B}) / \bar{B}$$

where B_i is biomass of age 3 and older fish and $\bar{B}$ is average biomass over the time series. Density dependent natural mortality is parameterized as

$$\log M_{ir} = M1_r + MU_r R_i$$

where MU_r is a parameter estimated by the model and $M1_r$ is the average level of fishing mortality during period r. The average level of instantaneous natural mortality was set to 0.45 for all stock reconstructions. Of the total annual mortality 0.40 was assigned to the first fishing period (r=1) and 0.05 to the second fishing period (r=2). For the baseline computer runs of the stock assessments the parameter MU_r is not estimated (ie. no density dependence is assumed).

Even with a fixed natural mortality rate the reconstructions for one of the stock groupings (north coast) showed increasing stocks through the time period to unrealistically high levels. To stabilize this tendency an additional term was added to the objective function to penalize for high numbers of 10-year old fish. The term:

$$- p \Sigma \ (N_{i,10,2})^2$$

was added to the objective function value with a penalty weight (p) of 1×10^{-4}.

Forecasts of spawning stocks in 1986 were calculated by assuming all natural mortality for the first period (0.40) will occur prior to spawning, and therefore prior to the roe fisheries. The numbers of fish at age prior to the fisheries are therefore the numbers estimated at the beginning of the 1985/86 season minus the number dying through the year. To account for partial recruitment of the younger age-classes (i.e. cohorts not fully mature) we use the proportion vulnerable at each age to the seine gear. We are therefore assuming that the seine gear fishes the spawning stocks non-selectively. This is generally true, though there may be a level of selectivity resulting from the seine fisheries occuring on the early spawning

groups which tend to have higher numbers of older fish. Age 3 recruits are predicted by the average number of age 3 fish estimated between 1971 to 1984. The proportion at age available to the seine gear is multiplied by the forecast numbers at age to obtain forecasts of fishable stock size. Biomass estimates are calculated by applying average weights at age to the estimated numbers at age.

3.3 STOCK RECONSTRUCTIONS

A new spawn index was evaluated for use in the 1985 stock assessments. The index, discussed in Hay and Kronlund (1985), uses a width and intensity factor which is standardized by section over the time series. This will remove bias in the spawn time series resulting from increased awareness of subtidal spawnings and from changes in the method used to estimate intensity, however, it may mask real changes in total spawn deposition. The performance of the age-structured model with Hay's spawn index was evaluated by comparing the total function value with those obtained using three alternate spawn indices. Model performance with these three alternate indices was discussed in last year's assessment document (Table 3.1, Haist et al. 1985). Comparision of all spawn indices, using the same stock groupings as in previous assessments indicate the Hay index provides a better fit to the model assumptions for 4 of 5 stock groupings (Table 3.1). This index is used for all age-structured stock reconstructions in the 1985 assessments.

Spawning trends, that is, Hay's spawn index and the spawn estimated from escapement from the baseline runs of the stock reconstructions, are shown in Fig. 3.1 for current stock groupings. The stock reconstructions follow the general trends in the spawn index but do not adhere closely to the annual variations in this index. This results from the low penalty weight on the spawn relationships in this run of the model. Because variability between different indices of spawn can result in qualitatively different stock reconstructions (Haist et al. 1985), we feel it is generally better for the model to adhere more closely to information in the age-composition, than to the spawn index. However, there is a potential problem with stock reconstructions for the south coast stock groupings. All four south coast stocks indicate a substantial increase in spawners estimated by the model for 1985. This is contrary to both spawn assessments and pre-fishery hydroacoustic biomass estimates for these areas. Because of general concern with the current status of the south coast herring stocks two additional stock reconstructions incorporating different model assumptions were evaluated for alternative explanations to the observed age structure. The first alternate run includes a high penalty weight on the spawn components of the model for the last five years. The second alternate run evaluates the assumption of density dependent natural mortality. The underlying premise in incorporating this assumption is that as herring stocks decline natural mortality increases.

The computer runs assuming density dependence performed better in all cases than the general runs, that is, they had a lower objective function

value. For all stock groupings density dependence was inversely related to biomass, that is natural mortality increased as stock biomass decreased. The following table shows the estimated ranges in instantaneous natural mortality over the time series for all stock groupings:

Stock grouping	Natural mortality range
Skincuttle-Selwyn	0.14 - 1.28
Prince Rupert District	0.25 - 0.73
Central coast	0.33 - 0.60
Strait of Georgia	
- northern	0.27 - 0.86
- southern	0.36 - 0.53
West coast Vancouver Island	
- northern	0.30 - 0.59
- southern	0.10 - 1.50

3.4 STOCK STATUS AND FORECASTS

Recent trends in estimated escapement biomass for all three sets of stock reconstructions are compared with two spawn indices (Hay's spawn index and the standard square meters index (SSM) used by fisheries officers) for north coast stock groupings (Fig. 3.2). For the Skincuttle-Selwyn stock grouping the stock reconstructions from the three model runs are very similar, indicating a peak spawning biomass in 1981/82. Both spawn indices show peak spawning in 1980, however, the overall trend in observed spawn is similar to the trend in estimated spawning biomass. For the Prince Rupert area both the spawn indices and estimates of spawning biomass show a steady increase from 1979 to 1985. The SSM spawn index is somewhat more erratic than Hay's index which follows the spawning biomass estimates more closely. Stock reconstructions for the central coast indicate an increase in spawning biomass from 1979 to 1982 followed by a steady decline in stock levels. This trend is very similar to that from the SSM spawn index. Hay's index indicates that spawning has been steady since 1982.

For all three north coast stocks estimated spawning biomass is in general accord with at least one of the spawn indices, even for the runs without a high penalty weight on the spawn relationships. Forecasts of stock biomass in 1986 are therefore based on the average of the predictions from the low spawn weight and the density dependent stock reconstruction for the north coast stocks (Table 3.2). Because of the severe decline in spawning biomass in the central coast we recommend that the catch quota for this area should be based on age 4 and older fish only.

Comparison of recent trends in predicted spawning biomass for all three sets of stock reconstructions and the two spawn indices are shown in Fig. 3.3 for the southern stock groupings. For all four stock groupings the spawn indices indicate drastic declines in spawn between 1979 and 1985. The stock reconstructions from age-structured analysis show these stocks declining between 1979 and 1984, however, they show a significant increase in spawning

biomass in 1985. This results from a high proportion of juvenile fish in the biological samples in 1984 and 1985. The model interprets this as a large cohort entering the fishery (4-yr olds in 1986). However, there may be alternate explanations for the observed high proportions of juvenile fish.

Both spawn indices for the northern Strait of Georgia stock show a dramatic decline in recent years; the trend in spawners predicted from age-structured stock reconstructions is less severe (Fig. 3.3). The computer run with a high penalty weight on spawn for the last five years estimates a smaller increase in spawners between 1984 and 1985 than the other two runs. The two spawn indices for the southern Strait of Georgia stock are qualitatively very different. Hay's spawn index shows a decrease in spawn between 1979 and 1985, and follows the biomass trends estimated from age-structured analysis more closely.

The two spawn indices for the northern west coast of Vancouver Island stock are qualitatively similar and show a continuous decline in spawn between 1979 and 1985 (Fig. 3.3). Both the general stock reconstruction and that assuming density dependent natural mortality show an unbelievable increase in spawners between 1983 and 1985. The run with high spawn penalty weight is more in line with the trends in the spawn indices. The southern west coast of Vancouver Island stock is the only stock in the south coast where the spawn indices are higher in 1985 than in 1984. The stock reconstruction with a high spawn penalty weight shows a similar increase in spawning biomass as the indices. The two other reconstructions indicate a much bigger increase in spawners in 1985.

Because the stock reconstructions from age-structured analysis deviate strongly from the spawn indices for all south coast stocks we use only forecasts of 1986 abundance from the run with high penalty weight on the spawn relationships (Table 3.2). These are somewhat more in line with the trends in F.O. spawn assessments. These stocks all appear to have declined dramatically in recent years, with the possible exception of the southern west coast of Vancouver Island stock. For this reason we recommend that the 1986 catch quotas should be based only on estimates of returning adults.

Table 3.1. Objective function values for stock reconstructions evaluating alternate spawn indices.

Division	Spawn Index			
	Spawn 1 (length)	Spawn 2 (length x intensity)	Spawn 3 (length x width x intensity)	Hay's spawn index
Queen Charlotte Islands	1074.8	1061.8	1159.7	1071.6
North Coast	1102.5	1107.7	1122.4	1099.2
Central Coast	771.9	769.7	783.9	764.4
Strait of Georgia/ Johnstone Strait	820.0	809.8	854.6	785.8
West Coast of Vancouver Island	804.6	806.7	803.1	791.2

Table 3.2. Forecasts of 1986 stock biomass (in thousands of tonnes) using age-structured model analysis.

Stock grouping	1985 Spawners	1986 Forecast Age 4+	1986 Forecast Age 3	1986 Forecast Total
Queen Charlotte Islands Skincuttle-Laskeek				
run 1-Low spawn weight	15.8	14.1	7.0	
run 2-Density dependent mortality	20.2	18.1	4.1	
average of 2 runs	18.0	16.1	5.6	21.7
Prince Rupert District				
run 1-Low spawn weight	30.3	31.9	4.0	
run 2-Density dependent mortality	35.3	39.5	4.1	
average of 2 runs	32.8	35.7	4.1	39.8
Central Coast (migratory)				
run 1-Low spawn weight	21.9	19.1	6.1	
run 2-Density dependent mortality	23.8	20.1	5.2	
average of 2 runs	22.9	19.6	5.7	25.3
Strait of Georgia				
northern stock				
run 3-High spawn weight	22.8	17.3	10.9	28.2
southern stock				
run 3-High spawn weight	12.5	9.0	4.7	13.7
West Coast of Vancouver Island				
northern stock				
run 3-High spawn weight	11.4	8.6	6.0	14.6
southern stock				
run 3-High spawn weight	16.0	14.3	10.0	24.3

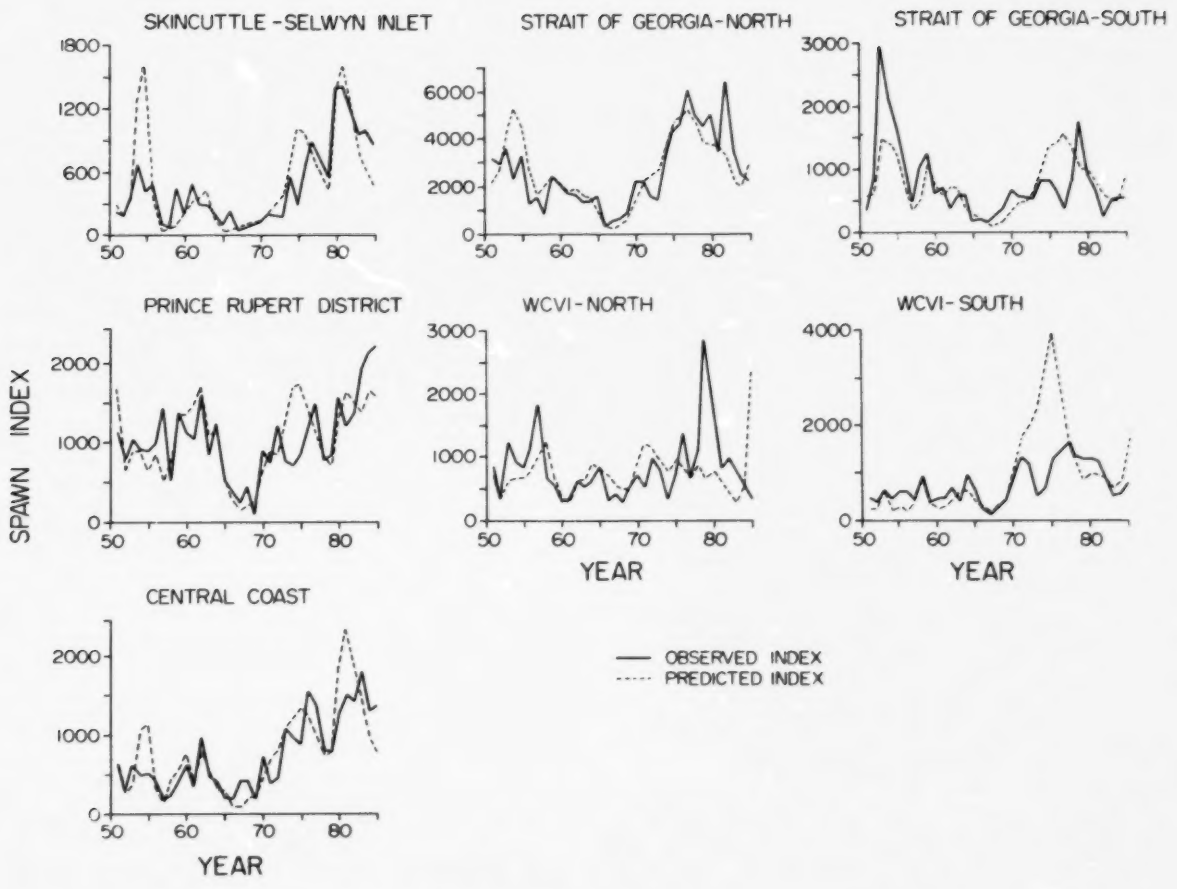

Fig. 3.1. Observed and predicted spawn indices from age-structured model analysis for B.C. herring stock groupings.

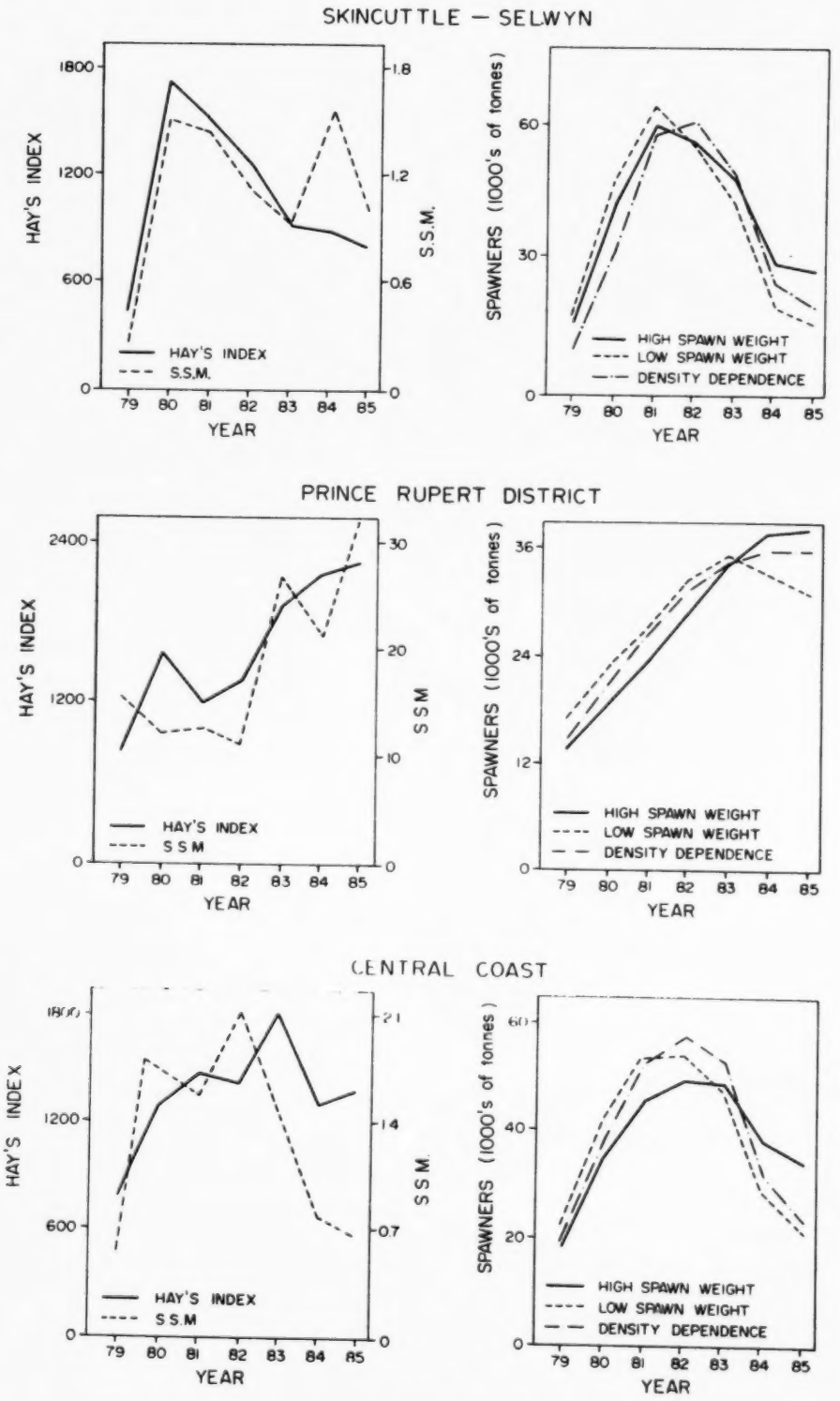

Fig. 3.2. Spawn indices (Hay's index and SSM) and estimated spawners from age-structured model for north coast stock groupings, 1975-85.

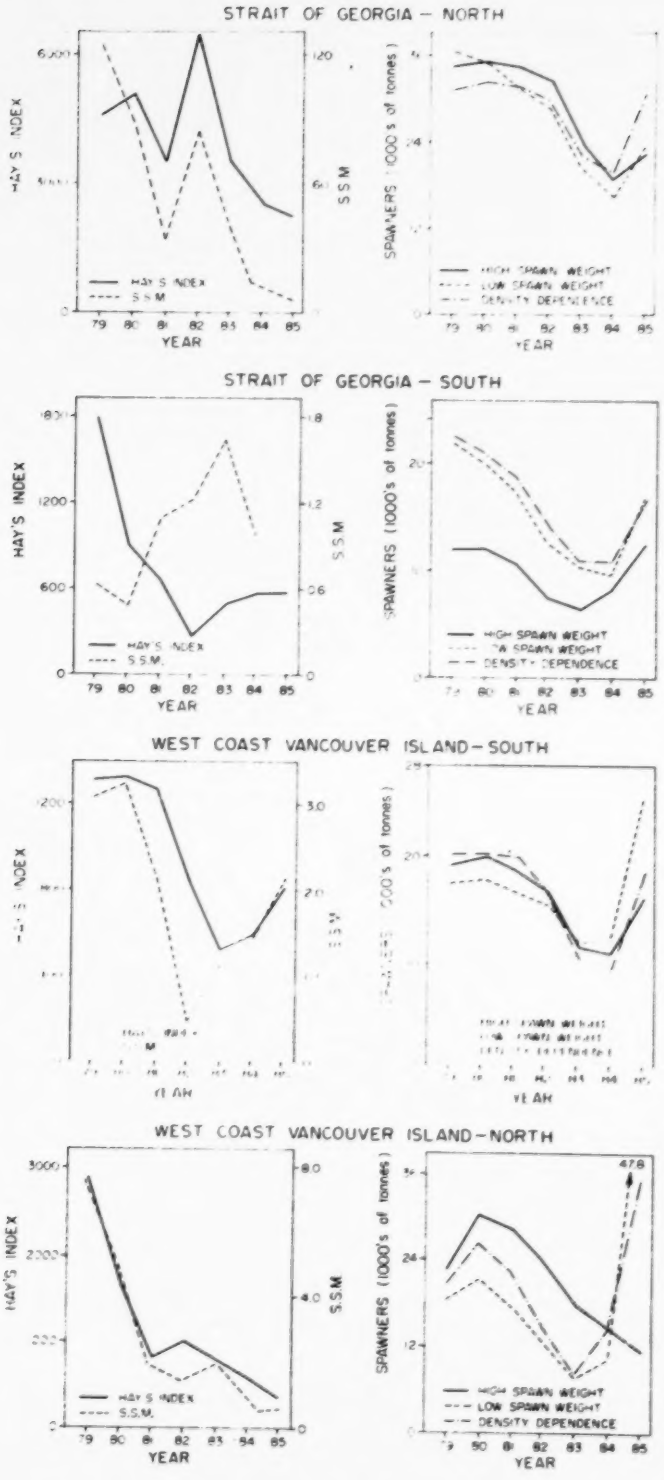

Fig. 3.3. Spawn indices (Hay's index and SSM) and estimated spawners from age-structured model for south coast stock groupings, 1979-85.

4. ESTIMATES OF EQUILIBRIUM BIOMASS IN THE ABSENCE OF FISHING AND CORRESPONDING CUTOFF LEVELS FOR B.C. HERRING

4.1 INTRODUCTION

This is an attempt to define levels of biomass for B.C. herring populations where the fishery should cease (i.e. CUTOFF levels). These levels should minimize the risk of reaching very low biomasses where reproduction potential is severely limited. CUTOFF levels should be high enough to allow large population growth for quick rehabilitation. The exact population level defining the CUTOFF is a matter of acceptable probabilities, rather than guarantees.

4.2 THE POPULATION MODEL

The production relationship is formulated as a relationship between the spawning escapement two years ago and the biomass of 2-yr olds produced using Ricker's formulation. A 2-variable model describes state transitions of 3-yr old herring and 4+ herring. Next year's fishable herring biomass will be the survivors of this year's escapment, corrected for growth, plus recruitment of 3-yr olds.

Five populations were modeled: Strait of Georgia and Johnstone Strait, west coast of Vancouver Island, central coast, Prince Rupert district and Queen Charlotte Islands. For each of the five populations, parameter values (growth, survival, and S-R parameters) were estimated from the 1984 runs of the age-structured model (Haist et al. 1985). For illustration, Fig. 4.1a shows the stock-recruitment relationship for the Strait of Georgia and Johnstone Strait population. The years indicated on the graph refer to year of birth of the 2-yr olds.

4.3 MODEL BEHAVIOUR

The combined effects of the production and population components can be visualized in a phase plane. This is a plot of the biomass of 4+ herring (A) against the biomass of 3-yr olds (F) with successive coordinate pairs representing different years. Fig. 4.2b shows the trajectories for three initial conditions. The trajectories were obtained through computer simulation by calculating each value of A and F from preceding values, using annual increments. The trajectories lead to an equilibrium biomass in the absence of fishing. Table 4.1 shows estimates of the equilibrium biomasses in the absence of fishing, for the five populations. The following is a comparison between the 1985 predicted "best" runs using the age-structured model (Haist et al. 1985:52) and the unfished equilibria:

	1985 Predicted run (1000 tonnes)	Unfished equilibrium (1000 tonnes)
Queen Charlotte Islands	31	52
Prince Rupert District	33	36
Central Coast	30	44
West coast Vancouver Island	21	83
Strait of Georgia and Johnstone Strait	27	86

4.4 CUTOFF LEVELS

CUTOFF levels are established to provide a substantial unfished reserve stock to protect against accidental overfishing and drastic declines that are occurring naturally (ie. El Nino events). Through long-term simulations using stochastic versions of the above models biologically acceptable CUTOFF levels appear to be at one-fourth of the unfished equilibrium biomass (Table 4.1). A harvesting strategy with these CUTOFF levels and a 20% harvest rate above CUTOFF has a number of desirable properties. It will keep average population size at a level well above the CUTOFF. The percentage of years in which the biomass will fall below CUTOFF will be minimal. The variance around the catch is relatively small, providing stability in the fishing industry.

These CUTOFF levels are preliminary, and should only serve as a guide in establishing quotas for the 1985/1986 herring season.

Table 4.1. Estimates of equilibrium biomass in the absence of fishing and corresponding CUTOFF levels for B.C. herring.

Area	Unfished Equilibrium Biomass (1000 tonnes)			CUTOFF (1000 tonnes)
	3-yr olds	4+ herring	total	
Queen Charlotte Islands	12.6	39.7	52.3	13.1
Prince Rupert District	8.6	27.0	35.6	8.9
Central Coast	11.0	33.4	44.4	11.1
Strait of Georgia and Johnstone Strait	20.6	62.6	83.2	20.8
West Coast of Vancouver Island	21.7	64.0	85.7	21.4

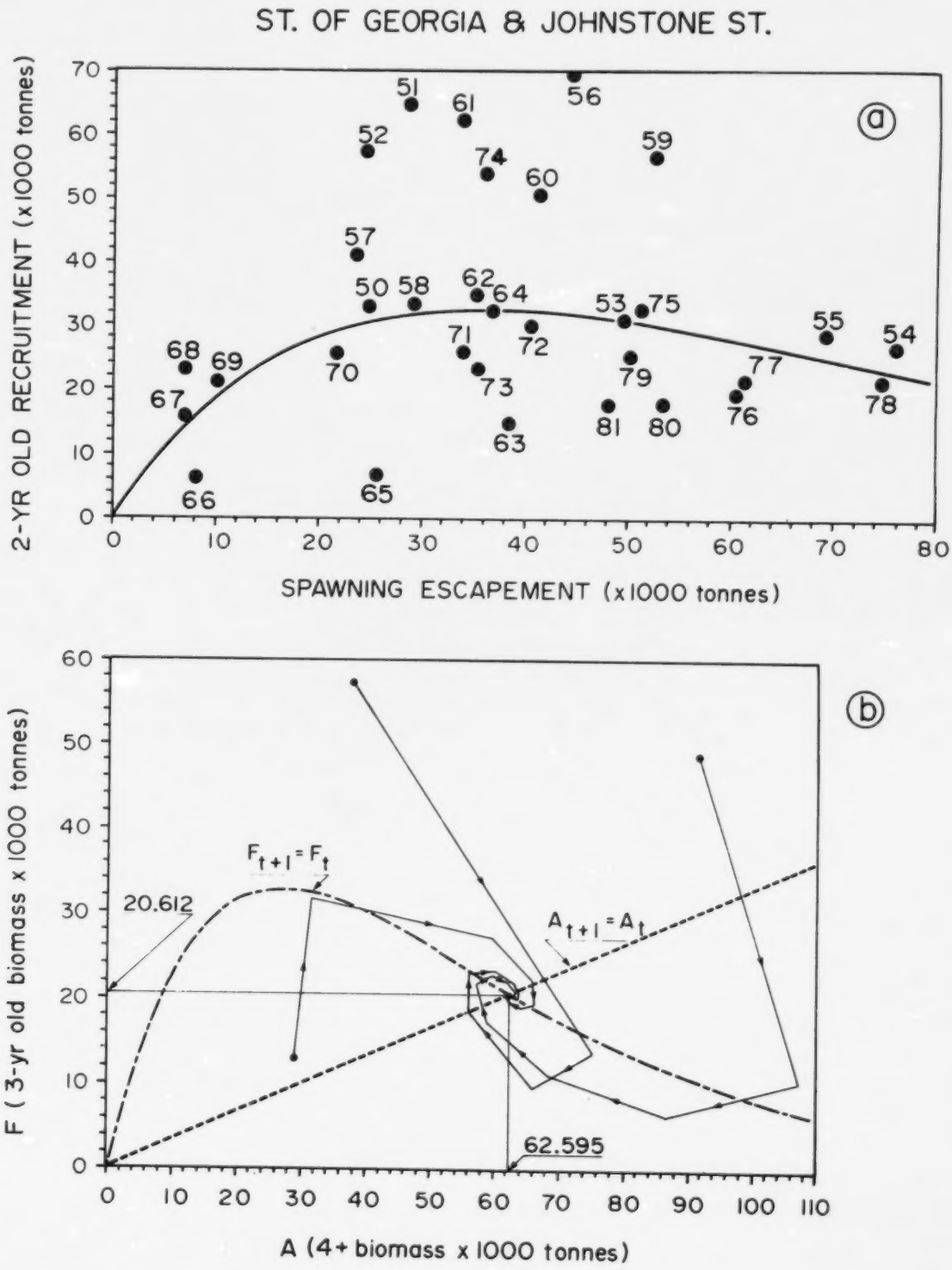

Fig. 4.1. (a) Ricker stock-recruitment relationship for Strait of Georgia/Johnstone Strait herring (datum from Haist et al. 1985). (b) Isoclines ($A_{t+1} = A_t$ and $F_{t+1} = F_t$), and unfished equilibrium (A = (2.595 and F = 20.612) biomass. A is 4 yr old and older, and F is 3 yr old herring biomass (x 100 tonnes).

5. CATCH RECOMMENDATIONS

We recommend catch levels at 20% of the "best" forecasts of the 1986 pre-fishery stock biomass for those stocks that are well above CUTOFF levels. The 20% harvest rate is based on an analysis of stock dynamics which indicates this level will stabilize both catch and spawning biomass while foregoing minimal yield over the long term. While a fixed escapement policy would provide the theoretical optimal solution, that is, highest yields and stock stability, this policy is not attainable at the operational level. For stocks that are marginally above CUTOFF we recommend the following catch:

Catch = Weighted Run - CUTOFF

This will provide for smaller fisheries for areas where 20% harvest rate would bring the escapement down to dangerously low levels.

To determine the "best" stock forecasts we used a two step procedure. First, for each of the two methods, and for each stock grouping, one production/recruitment scenario (ie. poor, average, or good) was chosen. Secondly, we assigned subjective probabilities to the two alternate assessment methods. Based on intuition, and past performance we believe that the age-structured model makes the most likely predictions of forecast runs. The escapement method makes a direct interpretation of spawn survey data, and has good predictive ability regarding returning spawners. However, the other component, predicting stock productivity, is probably not as well determined. We thus assigned subjective probabilities as follows:

Age-structured model	p(AS) = 0.60
Escapement method	p(ESC) = 0.40

The assigned probabilities were used to weight the forecast "best" runs obtained from each method to provide a single "weighted run" for each of the stock groupings (Table 5.1). Thus the resulting forecasts follow somewhat more closely the age-structure information, but still gives the current spawn information a high weight.

For the Skincuttle-Selwyn stock (Queen Charlotte Islands) the weighted run is predicted at 19,900 tonnes for a recommended catch of 4,000 tonnes. This is lower than last year's recommendation for two reasons. Firstly, the new stock grouping encompasses a smaller area, and secondly there is a downward trend in the stock. The Prince Rupert District stock is continuing to increase, and at least average production/recruitment is predicted (Stocker 1985). Thus, the weighted run is predicted at 33,200 tonnes, yielding a catch of 6,600 tonnes. In contrast to the southern areas, there appear to be no unfavourable environmental conditions affecting recruitment for these two northern stocks.

For the central migratory stock the weighted run is predicted as 17,000 tonnes. This low level reflects both, the new stock concept as well as the substantial decline of the stock. At this level, our recommendation is for a catch of 3,400 tonnes. It appears that the unfavourable environmental conditions in the south are also affecting the production of the Central coast stock.

On the south coast we are now experiencing the effects of the unusually warm water temperatures of 1983 in the form of low predicted production/recruitment for 1986 (Stocker 1985). Also, the escapement was very low on the south coast in 1985. The combined effect is for low forecast stock sizes of 21,600 tonnes and 19,300 tonnes for the Strait of Georgia, and the west coast of Vancouver Island respectively. For the Strait of Georgia the prediction is marginally above the CUTOFF level, and we recommend only a small catch of 800 tonnes (Table 5.1). As the predicted run size is below CUTOFF level for the west coast of Vancouver Island we recommend on purely biological grounds that the area be closed to fishing in 1986.

The catch levels recommended in this summary are based purely on biological considerations, reflecting the currently unfavourable environmental conditions in the south and Central coasts for herring production. We should point out that management of the various fisheries has practical constraints other than the biological considerations discussed in this report. Furthermore, there are certain economic considerations which we do not regard when making recommendations. Thus, the quotas recommended by the Stock Assessment Committee, and those ultimately adopted by DFO may differ from those recommended herein. We should also point out that the catch levels recommended herein include all fisheries. Catches from food, bait, and special fisheries must be subtracted from recommended catch levels to determine roe herring quotas.

Table 5.1. Summary of 1986 "best" predicted and weighted herring runs (1000 t) and the 1986 catch recommendation. (The "best" predicted runs reflect the current unfavourable environmental conditions.)

	Method									
	Age-Structured model				Escapement Method				1986	
		Forecast				Forecast with production[c]				
District	1985 Spawners	Adults	Age 3 recruits	Stock size	1985 Spawners	Low	Avg.	High	Weighted run	Recommended catch
Queen Charlotte Islands - Skincuttle - Selwyn	18.0	16.1	5.6	21.7	13.1	12.2	17.1[b]	22.1	19.9	4.0
Prince Rupert District	32.8	35.7	4.1	39.8	23.6	19.5	23.4[b]	27.4	33.2	6.6
Central Coast - migratory stock	22.8	19.6	5.7[a]	19.6	12.1	13.2[b]	19.4	25.7	17.2	3.4
Strait of Georgia - north	22.8	17.3	10.9[a]	17.3	7.8	10.3[b]	23.0	35.6	14.5	
- south	12.5	9.0	4.7[a]	9.0	4.7	4.2[b]	9.7	15.2	7.1	
- north/south combined	-	-	-	26.3	12.5	14.5	32.7	50.8	21.6	0.8[d]
West coast of Vancouver Island - north	11.4	8.6	6.0[a]	8.6	1.3	1.6[b]	7.0	12.5	5.8	
- south	16.0	14.3	10.0[a]	14.3	14.5	12.2[b]	25.6	38.9	13.5	
- north/south combined	-	-	-	22.9	15.8	13.8	32.6	51.4	19.3[e]	0

[a]Recruitment not included in forecast stock size
[b]"Best" predicted run by escapement method
[c]Recruitment (1970-85) from Table 2.3
[d]Weighted run - CUTOFF (CUTOFF see Section 4)
[e]Less than CUTOFF (CUTOFF see Section 4)

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